Journal of Forensic and Legal Medicine 20 (2013) 697–702

Contents lists available at SciVerse ScienceDirect

Journal of Forensic and Legal Medicine

journal homepage: www.elsevier.com/locate/jflm

Review

Forensic and clinical issues in the use of frangible projectile

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ARTICLE INFO

Article history:
Received 18 January 2013
Accepted 14 April 2013
Available online 10 May 2013

Keywords:
Ultra-frangible projectiles
Projectile fragmentation
Wound ballistics
Wounding effect of projectile
Gunshot wound

ABSTRACT

Frangible projectiles for firearms, which break apart on impact, are mainly used by law enforcement agencies for training purposes, but can also be used for police interventions. Apart from the usual absence of lead in the projectiles, the main advantage of using frangible projectiles is the reduced risk of ricochet after impact with a hard target. This article describes the design and function of frangible projectiles, and describes gunshot wounds caused by ultra-frangible projectiles which fragment after penetration of soft tissues. Shooting experiments performed by the authors confirmed that differences in the geometry and technology of frangible projectiles can significantly modify their wounding effects. Some frangible projectiles have minimal wounding effects because they remain compact after penetration of soft tissues, comparable to standard fully jacketed projectiles. However, a number of ultra-frangible projectiles disintegrate into very small fragments after impact with a soft tissue substitute. In shooting experiments, we found that the terminal behavior of selected ultra-frangible projectiles was similar in a block of ballistic gel and the soft tissues of the hind leg of a pig, except that the degree of disintegration was less in the gel.

1. Introduction

The range of the handgun ammunition with the non-lead projectiles made by the compression of a metal powder or a mixture of metal powders has been growing since the beginning of the 21st century. This specific type of ammunition, called as frangible ammunition, is designed to disintegrate on impact and are intended mainly for use during training by law enforcement agencies because of their relative safety (low ricochet hazard) and low toxicity.[1,2] However, new types of frangible ammunition that have been developed for combat situations and self-defense have also recently appeared on the market. Most frangible ammunition has been designed for handguns, but recently frangible ammunition for rifles has also been developed.[1–3]

Both medical and forensic experts must be made aware of the new injury patterns resulting from the use of frangible projectiles. Even when the projectiles do not leave the body, only small fragments can be found in the wounded tissues.[2–4] Frangible projectiles present a wide range of new technical challenges to the field of ballistics analysis.[2] From a criminological point of view, the most important disadvantage of frangible ammunition is the very limited ability to identify ballistic traces on the surfaces of fragmented projectiles.[1,2,4]

The aim of this article is to draw attention to the existence of frangible and ultra-frangible ammunition. The first part of this article describes the design and function of frangible projectiles. The second part reports the results of gunshot wounds caused by ultra-frangible projectiles in blocks of ballistic gel and the hind leg of a pig.

2. Design and properties of frangible ammunition

Frangible projectiles are generally designed to disintegrate after impact with a hard target. The resulting fragments are significantly smaller than the original projectile.[1–3,5]

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http://dx.doi.org/10.1016/j.jflm.2013.04.006

Fig. 1. Different types of 9 mm Luger pistol projectiles. The five projectiles on the left were made with copper powder, and the two projectiles on the right were made with iron powder.

Frangible ammunition is unique because of its terminal ballistic properties.[3,4] The projectiles show only limited penetration capability and have a reduced ricochet hazard because they fragment after impact with a hard target.[1,2,5] The ballistic properties of frangible projectiles depend on their specific manu facturing processes. Frangible projectiles are mainly manufactured by powder metallurgy (usually cold molding) of composite materials based on fine metal powders (including copper, iron, zinc, tin, bismuth, and tungsten; Fig. 1). Frangible projectiles are considered to be relatively ecologically sensitive because they have no lead content.[1,2]

For the non-professional, it is often very difficult to visually distinguish frangible projectiles from full metal jacketed projectiles with a lead core (Fig. 2), which could lead to mistakes. Some frangible projectiles can be recognized by their characteristic shape and color, and frangible projectiles usually have a flat point nose.[1–3] The nature of projectiles can only be reliably determined by special testing (such as hardness testing, fragility and strength testing, or microscopic inspection).

A classical compact frangible projectile usually fragments after impact with a rigid, hard target. The size of the created fragments is closely related to the rigidity of the target (Fig. 3). Standard frangible projectiles do not usually disintegrate after impact with a low-rigidity target (such as a thin metal sheet, wooden plate, glass window, or porous building materials). In cases of impact with a high resistance hard target (such as a thick metal sheet, armor plate, concrete or brick wall, or automobile windscreen), frangible projectiles disintegrate into a large number of small fragments which do not usually penetrate the target.[1–3] The fragmentation pattern is influenced by the impact velocity and impact angle of the projectile. The size of the fragments usually decreases as the impact velocity increases.

The most common frangible projectiles do not fragment or deform after penetration of soft tissues.[4] In this regard, their behavior in soft tissues is very similar to the behavior of standard full metal jacketed projectiles. Frangible projectiles may fragment after impact with bone, in the same way as after impact with other hard targets.[4] However, some frangible projectiles with a suitably shaped cavity in the front part disintegrate into a large number of fragments after penetration of soft tissues, even if they do not make contact with bone. These are known as ultra-frangible projectiles. The first ultra-frangible projectiles have recently been developed, tested, and used. Examples of ultra-frangible projectiles include the American commercially manufactured Extreme Shock Fang Face (FF) and Air Freedom Round (AFR) and the experimental frangible SRK-2 projectiles, manufactured in the Czech Republic (Fig. 4). The FF and AFR projectiles (Fig. 5) are intended for use by both law enforcement agencies and the general public (for training, self-defense, and hunting). The Varmint Grenade rifle ammunition, consisting of a brass jacket filled with a lightly compressed mixture

Fig. 2. Appearances of frangible projectiles (left) and classical full metal jacketed projectiles with a lead core (right). The back row on the right shows three fired projectiles, with deformation of the frontal part and grooves from the barrel rifling (all projectiles are for a 9 mm Luger pistol).

Fig. 3. Frangible projectile for a 9 mm Luger pistol made with copper powder. The image on the right shows disintegration of the projectile after hitting a hard target of lower ballistic resistance.

Fig. 4. Experimental frangible projectiles from the Czech Republic. Left: standard flat nose projectile. Right: three ultra-frangible hollow point projectiles (ultra-frangible SRK-1 projectile with a small-diameter cylindrical cavity, ultra-frangible SRK-2 projectile with a larger diameter cylindrical cavity, and ultra-frangible SRK-3 projectile with a shaped cavity).

of copper and tin powders, which is produced by the Barnes Company, has similar design and performance features (Fig. 6).[2]

Ultra-frangible projectiles typically disintegrate into fragments when shot into blocks of soft tissue substitute (such as ballistic gel) or animal body parts. This feature was extensively tested during their development.[1,5,6] It is therefore probable that they will also disintegrate when shot into human soft tissues. Ultra-frangible projectiles shot by handguns and especially rifles

Fig. 6. Varmint Grenade rifle projectiles.

create temporary large-volume cavities in blocks of ballistic gel, which often completely destroys the block. The wounding effects of these projectiles are comparable with those of explosive projectiles.[1,2]

3. Wounding effects of frangible and ultra-frangible projectiles

Properly designed frangible projectiles have the correct ratio of strength and toughness to deformation capability and brittleness.[1,2] Frangible projectiles must be compact and strong enough to withstand the load during the shot, the free flight to the target, and tissue penetration, and must also be brittle enough to reliably fragment after impact with a defined hard target.

The compactness of the brittle material in the frangible projectile has a significant effect on the wounding effects during both soft tissue penetration and impact with bone.[6,7] The projectiles cause significant wounding effects during disintegration in soft tissues owing to tissue damage caused by the large-volume of the temporary cavity.

Unlike compact projectiles, ultra-frangible projectiles do not create a classical wound channel during tissue penetration. Instead, the fragments create dozens of smaller wound channels.[4,6,7] The large numbers of irregularly shaped fragments cause a large-volume cone-shaped wound, which damages muscle fibers, nerves, and vessels. The penetrating capability of these particles is limited, and depends on their size and mass. A pistol projectile may reach a depth of up to 15 cm. Ultra-frangible projectiles do not exit the body, and therefore present no risk to bystanders. The risks of

Fig. 5. Extreme shock ultra-frangible pistol projectiles that fragment in soft tissues. Left: Fang Face cartridge. Right: Air Freedom Round cartridge.

causing serious wounds to bystanders through the ricocheting of small fragments and powder after impact with a hard target are minimal.

To analyze the wounding potential of ultra-frangible projectiles, we performed a shooting experiment. We fired projectiles from a ballistic measuring device into blocks of ballistic gel and the hind leg of a pig. The distance between the muzzle of the barrel and the target was 5 m, and the projectile's velocity at the distance 2.5 m from the muzzle of the ballistic measuring device was measured. We used SRK-2 experimental cartridges (Fig. 4) containing iron powder. The mass of the projectile with the frontal conical cavity was 4.8 g (74 grain bullet, caliber 9 mm Luger).

Fig. 7 shows a block of ballistic gel hit by an SRK-2 ultra-frangible projectile of mass 4.8 g and impact velocity 440 m/s. The projectile disintegrated into one larger fragment of approximately 50% of its mass and tens of smaller fragments that scattered in a conical shape because of the radial forces acting on them. The effects of centrifugal forces caused by the projectile's rotation were not significant. The maximum depth of small fragment penetration was 10 cm, and only the biggest fragment, which originated from the rear part of the projectile, penetrated right through the block. If the projectile had been shot into a human body, the large fragment would have been capable of reaching the central organs, but its remaining kinetic energy would have been relatively low.

Fig. 8 shows two frames (0.65 ms and 1.5 ms after projectile impact) from the high-speed camera records, demonstrating the size of the resulting temporary cavity and the directions of travel of the fragments through a block of ballistic gel. The depth of penetration depended on the weight of the fragments, with the heavier fragments penetrating deeper.

Figs. 9–11 show the wounding effects of an SRK-2 projectile (9 mm Luger). The ultra-frangible projectile impacted with the hind leg of a pig at 455 m/s. The results were similar to those of impact with a block of ballistic gel except that the whole projectile, including the rear part, disintegrated into small parts without reaching the bone.

Most frangible projectiles (except ultra-frangible projectiles) can be dangerous to bystanders located behind intermediary targets of lower ballistic resistance (such as automobile windscreens, and doors and windows of buildings). Although the projectile disintegrates on impact with the obstacle, the fragments may endanger the face and neck of a person behind the obstacle.[3] The fragments travel in a conically shaped cluster (ultra-frangible projectile fragments travel similarly to those of explosive fragmentary ammunition) and therefore present some risk to bystanders in close proximity.

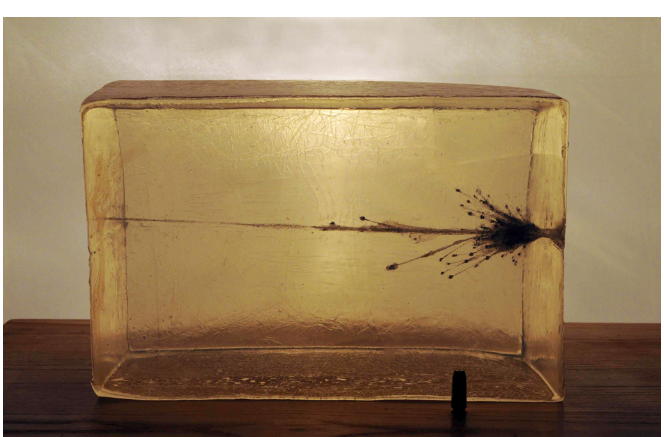

Fig. 7. Results of shooting an ultra-frangible projectile into a 30-cm block of ballistic gel. The projectile traveled from right to left. A high-speed camera recording is available at, http://rucevzhuru.cz/index.php/video/balistika/226-video-strela-ultrafrangible-v-gelu.html.

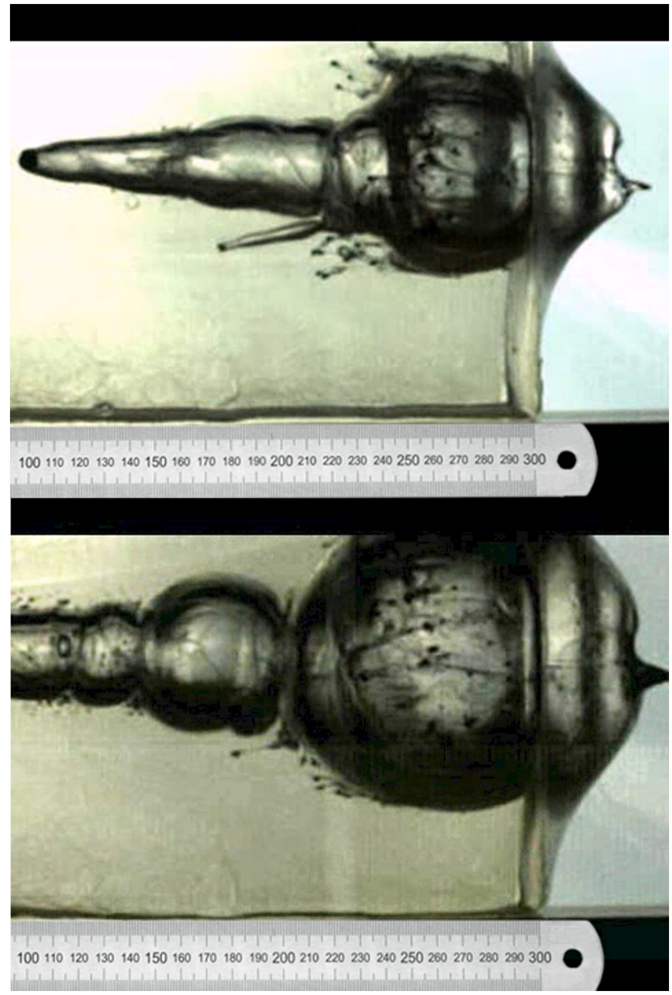

Fig. 8. Temporary cavity formed during disintegration of an ultra-frangible projectile. Top: 0.65 ms after impact. Bottom: 1.5 ms after impact. The velocity of the rear part of the projectile was approximately 200 m/s.

Ultra-frangible projectiles exhibit specific properties in terms of wound ballistics and traumatology as listed below[1–3,5,7]:

- Ultra-frangible projectiles usually disintegrate immediately after penetration of soft tissues, at which point the load on the projectile is highest due to the hydrodynamic pressure. The moment and degree of fragmentation are unique and difficult to predict.
- In more compact and less fragile projectiles, disintegration may not occur until impact with harder tissues (such as bones, teeth, or fibrous fascia).
- Impact of ultra-frangible projectiles with relatively resilient clothing (such as buttons or belts) may cause early disintegration before they even enter the body.
- If a highly fragile projectile fails to fragment when penetrating soft tissues or ballistic gel, it creates a temporary tubular-shaped cavity similar to that caused by a jacketed projectile of the same caliber.

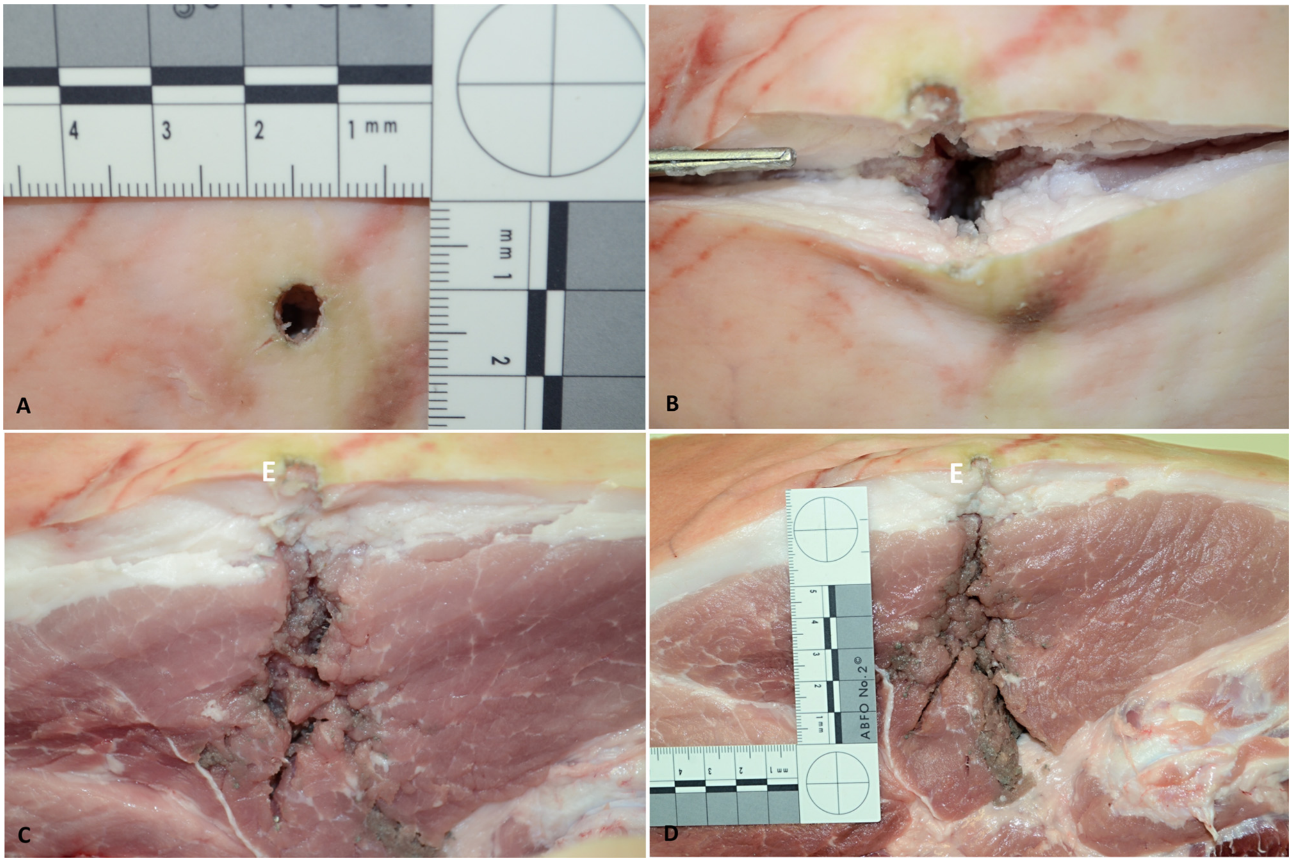

Fig. 9. (A, B) Entry wound on the hind leg of a pig (SRK-2 ultra-frangible projectile, 9 mm Luger). (C, D) Longitudinal cut through the wound channel showing corroding projectile fragments. E indicates the entry wound.

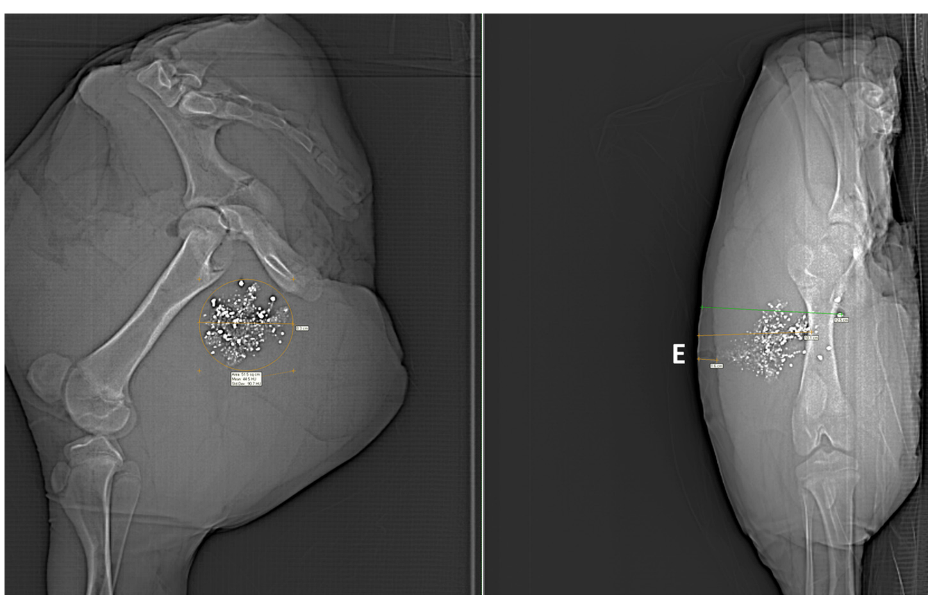

Fig. 10. Localizing CT projection radiograph of the wound on the hind leg of a pig (SRK-2 ultra-frangible projectile, 9 mm Luger) showing disintegration of the projectile. E indicates the entry wound. Left: frontal view in the direction of projectile motion. Right: side view perpendicular to the longitudinal axis of the leg.

- When an ultra-frangible projectile disintegrates after penetrating soft tissues or ballistic gel, the minor fragments cause tens of small projectile channels (the effect is comparable to that of a shower of small pellets or an explosive projectile).
- Minor projectile fragments weighing several tenths of a gram each penetrate the soft tissues in cone-shaped area to a depth of 10–15 cm. A larger fragment weighing several grams penetrates the tissues to a much greater depth than a minor fragment (unless the larger fragment exits the body).

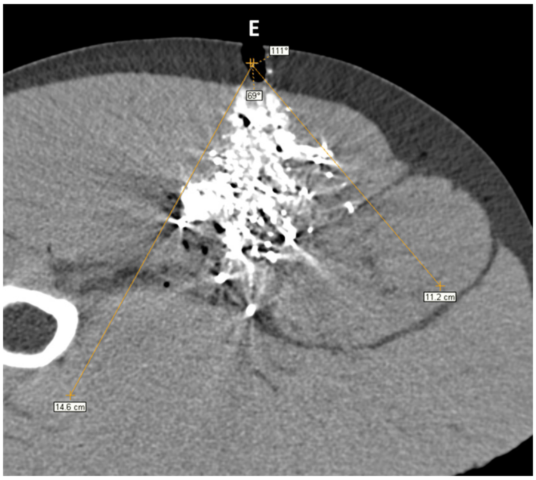

Fig. 11. Longitudinal axis CT image of the wound on the hind leg of a pig (SRK-2 ultra-frangible projectile, 9 mm Luger) showing disintegration.

- Identical projectiles may cause variable wounding effects depending factors such as impact velocity, impact location, and intermediary target.

4. Conclusion

Information about the wounding effects of these types of ammunition is very sparse to date. In our shooting experiments, we found that the terminal behavior of selected ultra-frangible projectiles was similar in a block of ballistic gel and the soft tissues of the hind leg of a pig, except that the degree of disintegration was less in the block of ballistic gel. As a large variety of frangible ammunition is being designed and its commercial availability will probably expand in the near future, it is likely that injuries resulting from the use of this ammunition will become more common, ranging from uncomplicated limb injuries to fatal internal organ injuries. The increased worldwide use of ultra-frangible projectiles with high wounding effects will require further research of associated technical, forensic ballistic, medical, and legal issues.

Ethical approval
None.

Funding
None.

Conflict of interest
None.

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